AUGUST 2021

TD21-021

Inspection of Ballast Pockets

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The research described was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

Key Findings:

- Track geometry data from the previous seven years was helpful in identifying problem regions so future remediation can be optimized.
- For locations where the ballast pocket is deep and/or the ballast layer is fine filled and moist, GPR and DCPT complement each other because they emphasize different characteristics of the ballast pocket.
- GPR measures large areas quickly and can identify rapid changes in subgrade conditions along with details on the ballast fouling and drainage condition. GPR identifies layer interface depths well but is not able to measure depths near to or greater than 6 feet.
- DCPT fully characterizes the track subgrade to depths of 15 feet while providing images and videos to help interpret the ballast condition.

In 2018, BNSF Railway and TTCI compared ground penetrating radar (GPR) and dynamic cone penetration testing (DCPT), two ballast and subgrade inspection methods, to determine how these methods would evaluate a ballast pocket location in the southern United States. The comparison also identified the benefits and drawbacks of each method. The objective of this research was to help optimize ballast pocket inspection using various available inspection methods.

BALLAST POCKETS

Ballast pockets are a common subgrade issue, and they often experience higher track geometry degradation rates than typical track and therefore require more track maintenance, leading to lower operational capacity. Effective subgrade remediation techniques are available, and the geometry degradation at ballast pockets can often be significantly reduced if their root cause is identified and addressed.[1] To identify the problem region, an investigation is often required to characterize the site.

The underlying mechanism producing ballast pockets is typically a soft-subgrade embankment that progressively deforms vertically and laterally over time.[2] Soft-subgrade embankments often result from the initial construction when current geotechnical knowledge and quality subgrade materials are unavailable and the large increase in loading and traffic volumes is unanticipated. In order to restore the track geometry elevations, new ballast is added during track maintenance.

This restoration can develop into a ballast pocket over time. Ballast pockets can range from a local two-foot section to a section over eight feet deep that spans hundreds of feet. These pockets often trap water within the pocket, commonly referred to as the “bathtub effect,” which keeps the subgrade material at the ballast-subgrade interface at a high-moisture level. This high level of moisture can cause a weakness in the interface that would not have been present had the material been dry.

Successful ballast pocket remediation often requires knowing not only the ballast condition but also the subgrade strength before drain installation. Ballast drains are not always effective if the subgrade is still too soft or if the ballast layer is fine-filled. Ballast pockets can also be uneven with multiple low spots, thus even good ballast drain targeting and placement can leave pockets of high-moisture material.

Successful remediation strategies to reduce the progressive deformation include: increasing embankment strength by removing excess water using ballast drains; directly increasing embankment strength using subgrade stabilization methods (e.g., grout columns); or reducing the stress on the embankment by improving stress distribution with upper ballast stabilization methods such as geosynthetics or hot mix asphalt (HMA).

BLUE CUT TEST SITE

The analysis was performed on a site called Blue Cut located on BNSF track. The site is categorized as Class 4 track and carries primarily mixed freight and passenger traffic. The majority of the track section is on an embankment that reaches up to 40 feet tall but also includes some cut regions (see Figure 1).

Figure 1. Blue Cut Test Site

The site was selected because it has been experiencing recurring track geometry issues and slow orders. A review of track geometry records (that was corroborated with the track supervisor) showed the primary issues were surface and cross level in spirals and tangent track.

Track geometry exceptions were also analyzed from 2012 to 2019 and showed three major regions with track geometry issues (labeled R-1, R-2, and R-3). These regions are generally tangents and spirals. Figure 2 shows the number of track geometry exceptions for each 0.1-mile section. The red bars indicate curve regions while black bars represent tangents and spirals. The orange lines will be discussed later.

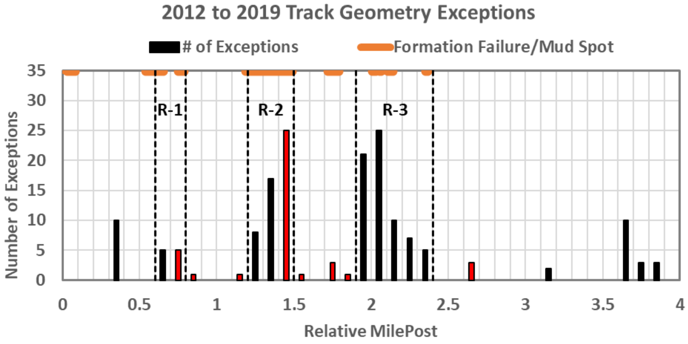

Figure 2. Locations of track geometry exceptions along with track curvature and GPR formation failure locations

Soil maps of the area show the surrounding soil to be plastic, expansive, and its strength is highly moisture-dependent. These are characteristics that are often found in embankments with ballast pockets. Site observations showed an uneven embankment surface that is possibly from embankment bulging, but it was difficult to assess with the high levels of vegetation and not knowing when the bulging occurred (e.g. 50 years ago or last week). Cattails were common on the east side of the track and vegetation was prevalent on both sides. The cattails and vegetation suggest potential high moisture levels in the embankment.

INSPECTION RESULTS

To diagnose the Blue Cut site, two inspection methods were used: GPR and DCPT. These methods were selected because they are common railroad substructure inspection methods and both tend to be less expensive and more accessible than traditional cone penetration tests (CPT) and soil investigation methods.[3]

GROUND PENETRATING RADAR RESULTS

GPR is a track-based inspection system that characterizes the substructure by analyzing radar wave reflections. For this site, three metrics were analyzed: 1) Ballast Fouling Index (BFI), 2) free draining layer (FDL), and 3) interface depths. BFI was measured using 2-GHz antennas and estimated the amount of fouling particles in the top 16 inches of surface. FDL also used the 2-GHz antennas and estimated the depth of clean ballast up to a depth of 16 inches. The interface depths used the 400-MHz antennas and estimated the various interface depths up six feet. These three metrics were used to diagnose the ballast and subgrade layers.

In addition to the three metrics, the GPR vendor also provided information on where they believed mud spots were located based on the GPR results. These locations are shown in Figure 2 as orange lines at y=35. The region of mud spots appears to line up well with the track geometry exceptions.

To analyze the BFI and FDL results, the values were compared with the number of track geometry exceptions that occurred at Blue Cut from 2012 to 2019, as shown in Figure 3. BFI (Figure 3a) is defined as percentage of fines that pass the #4 sieve plus the percentage of fines that pass the #200 sieve.[2] FDL (Figure 3b) is defined as the depth of clean ballast and is simplified into three categories: good (FDL>14 inches), poor (FDL 8–14 inches) and very poor (FDL<8 inches).

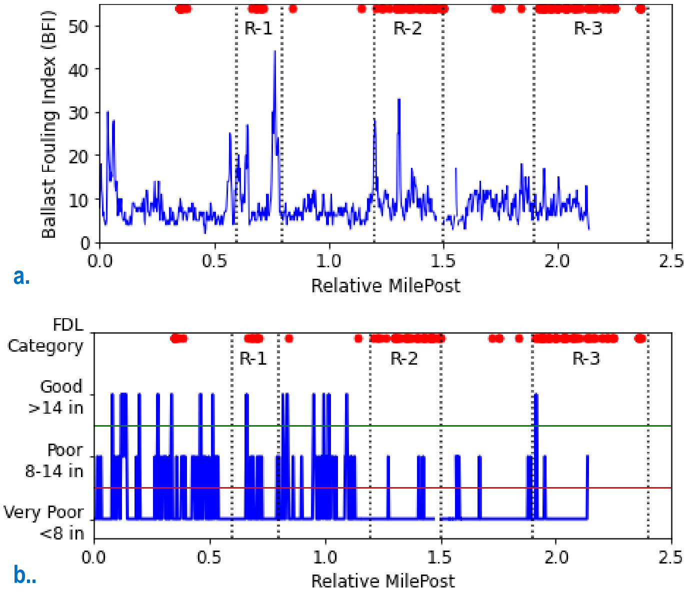

Figure 3. (a) BFI and (b) FDL, compared against track geometry exceptions (red circles) on two-mile section

Both BFI and FDL show some correlation with track geometry exceptions but at different regions. The track BFI has spikes in R-1 and R-2 while FDL is lowest (very poor category) in R-2 and R-3. This is not surprising because while the root cause of the track geometry issues are likely due to deep ballast pockets, the track settlement and water retention may also accelerate ballast deterioration in those areas causing surface ballast issues along with the deeper ballast pocket issues. This emphasizes how issues in one part of the track system can negatively impact other track components in that problem region.

DYNAMIC CONE PENETRATION TESTING RESULTS

The dynamic cone penetration testing (DCPT) performed at Blue Cut used an optical instrument system called the Pandoscope®. The Pandoscope consists of two parts: the PANDA® DCPT system and a geo-endoscope which is lowered into a hole made by the DCPT system in order to capture videos and photos of the ballast/subgrade condition including depth. This allows investigators to literally "see" beneath the surface. An additional benefit is that the Pandoscope system can be moved without a truck or hi-rail, making logistics easier and reducing track time.

The DCPT soundings were taken at nine pre-selected locations based on GPR data. Figure 4 compares the GPR and DCPT system ballast pocket depths along with the number of exceptions. The results show a large difference between the two methods as the DCPT system can potentially measure up to 15 feet deep, which is much deeper than the six-foot limit of the GPR system.

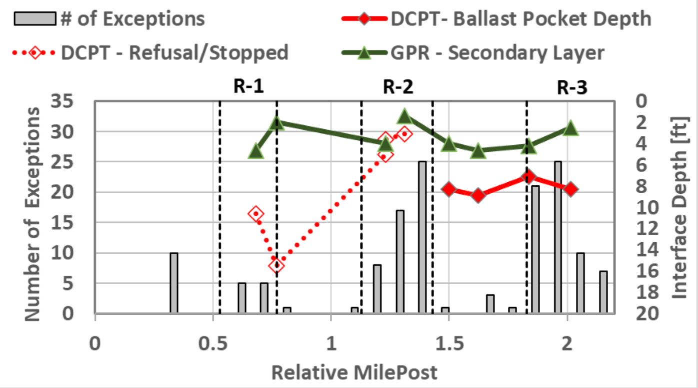

Figure 4. Comparison on layer interfaces from GPR and DCPT system

As illustrated in Figure 5, If the DCPT system did reach the subgrade, the ballast pocket depths are clearly shown from the cone resistance plots. At relative milepost (MP) 0.68 and MP 0.7, the DCPT was stopped before reaching the clay embankment material so the depth of the ballast pocket is not known. At MP 1.23 and 1.31, refusal was encountered; this may have been due to some sort of stabilizer added in the past. Unfortunately, this condition did not allow for analysis of the location with track geometry exceptions. The results showed that R-1 had the deepest ballast pockets extending down to 15 feet deep; R-2 had unknown depths because of refusals; and R-3 had depths of about eight feet.

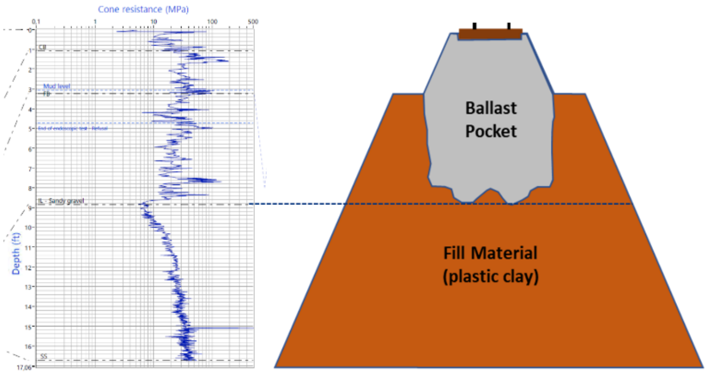

Figure 5. Results showing DCPT identifying the ballast pocket depth

The cone resistance of the subgrade soil at the ballast-subgrade interface ranged from 3.5 to 10 MPa (500–1,450 pounds per square inch, or psi). The California Bearing Ratio, a representation of subgrade strength from penetration tests, is estimated to be 5 to 13.5 from these cone resistance values. Previous experience with the DCPT suggests that soils with a cone resistance less than 10 MPa is considered soft. That means the soil at the bottom of the ballast pocket is prone to deformation.

GPR/DCPT COMPARISION

A comparison of GPR/DCPT shows that the GPR track-based system allows for an analysis of the entire track section while DCPT can only measure specific spots. GPR appears adept at characterizing the ballast condition (to a depth of 16 inches) because of the BFI and FDL outputs while the cone resistance output from the DCPT is only applicable to deeper subgrade soil. However, the geo-endoscope video gives additional information on ballast conditions. The predicted layer interface depths from the GPR and DCPT were similar to a depth of six feet but only the DCPT system was capable of measuring the ballast-subgrade interface depth if greater than six feet.

The results of this study show that that GPR and DCPT are effective at measuring different aspects of the ballast pockets and suggests that these systems are complementary to each other. Both systems are likely required if ballast pockets are greater than six feet deep.

References

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